ISSN 1063-7850, Technical Physics Letters, 2018, Vol. 44, No. 2, pp. 164–166. © Pleiades Publishing, Ltd., 2018.
Original Russian Text © A.I. Saifutdinov, B.A. Timerkaev, A.R. Ibragimov, 2018, published in Pis'ma v Zhurnal Tekhnicheskoi Fiziki, 2018, Vol. 44, No. 4, pp. 74–79.

Numerical Simulation of Temperature Fields in a Direct-Current Plasma Torch

A. I. Saifutdinov[a, b]*, **B. A. Timerkaev**[c], **and A. R. Ibragimov**[a]

[a] *Kazan Federal University, Kazan, Tatarstan, 420008 Russia*
[b] *St. Petersburg State University, St. Petersburg, 199034 Russia*
[c] *A.N. Tupolev Kazan National Research Technical University, Kazan, Tatarstan, 420111 Russia*
**e-mail: as.uav@bk.ru*

Received August 7, 2017

Abstract—Thermal characteristics of a direct-current plasma torch have been studied in the framework of numerical simulations of temperature fields in a plasma channel, cathode, and anode. It is established that the temperature of the operating cathode surface exceeds the melting temperature of the cathode material.

DOI: 10.1134/S1063785018020281

Plasma torches of various types have been widely used for many years, in particular, in metallurgy for hardening metal surfaces, plasma deposition of coatings, obtaining fine powders, cutting metals, etc. [1–3]. The variety of applications determines wide range of requirements to the properties of plasma torches. A long operation life of a plasma torch is directly related to that of its heavy-duty elements, in particular, electrodes. The thermal state of the surface and the magnitude and character of erosion of thermionic cathodes in high-current plasma torches determine their performance characteristics and working life. The interacting system of electrode and near-cathode plasma is a complicated object of investigation that is characterized by strong spatiotemporal inhomogeneity. Inhomogeneous temperature fields on the surface of thermionic cathodes can lead to the appearance of local overheated zones, evaporation of the cathode material, its cracking and fracture, and a number of other processes and phenomena determining the working life of cathodes.

For these reasons, spatiotemporal analysis of temperature fields on the surface of cathodes generating high-current electric arcs is a topical task. Numerous investigations have been devoted to determination and optimization of plasma torch characteristics. However, despite the considerable progress that has been made in modeling direct-current plasma torches [4–8], the temperatures of the inner surfaces of plasma torch electrodes are still typically set to be constant and their inhomogeneous heating due to processes at the boundary of arc plasma is ignored.

The present work was devoted to numerical simulation of the main characteristics of dc plasma torches, in particular, self-consistent determination of the distribution of temperature fields in electrodes. The model was based on the system of Navier–Stokes equations (including the equation of continuity, equations of motion, and equation of heat transfer in the plasma jet) supplemented by the system of Maxwell equations for the electric and magnetic fields, the differential Ohm's law, and the equations of heat balance in a metal cathode and anode:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{V}) = 0, \tag{1}$$

$$\begin{aligned} \rho\left(\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V}\cdot\nabla\mathbf{V}\right) &= \mathbf{j}\times\mathbf{B} \\ &- \nabla\left[P + \frac{2}{3}\mu(\nabla\cdot\mathbf{V})\right] + 2\nabla(\mu S), \end{aligned} \tag{2}$$

$$\begin{aligned} \rho c_p\left(\frac{\partial T}{\partial t} + \mathbf{V}\cdot\nabla T\right) - \frac{dP}{dt} &= \nabla(\lambda_2\nabla T) \\ &+ \mathbf{j}\times\mathbf{E} + \frac{5k_{\mathrm{B}}}{2e}\mathbf{j}\cdot\nabla T - Q_{\mathrm{rad}}, \end{aligned} \tag{3}$$

$$\begin{aligned} \nabla(\sigma\nabla\varphi) = 0, \quad \mathbf{E} = -\nabla\varphi, \quad \mathbf{j} = \sigma\mathbf{E}, \\ \nabla^2\mathbf{A} = -\mu_0\mathbf{j}, \quad \mathbf{B} = \nabla\times\mathbf{A}, \end{aligned} \tag{4}$$

$$\rho_{c,a}c_{pc,pa}\left(\frac{\partial T_{c,a}}{\partial t}\right) = \nabla(\lambda_{c,a}\cdot\nabla T_{c,a}). \tag{5}$$

Here, ρ, ρ_c, and ρ_a are the densities of the gas and the cathode and anode materials, respectively; t is the time; $\mathbf{V}$ is the velocity vector; $\mathbf{B}$ is the magnetic-induction vector; P is the gas pressure; μ is the dynamic viscosity; c_p, c_{pc}, and c_{pa} are the heat capacities of the gas, cathode, and anode, respectively, at constant pressure; T, T_c, and T_a are temperatures in the plasma channel, cathode, and anode, respectively; $\mathbf{E}$ is the